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Genetic Connections of Anomalous X-ray Pulsars and Soft Gamma Repeaters with Supernova Remnants

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Abstract. Genetic connections between anomalous X-ray pulsars (AXPs) or soft gamma repeaters (SGRs) and supernova remnants (SNRs) can hold important clues to the nature of these objects through the properties of the associated SNRs. We examine various criteria jointly to assess the reliability of possible connections. 3 AXPs and 2 SGRs are most probably genetically connected with SNRs. Distances and ages are discussed and their likely ranges are indicated.

Key words. AXP – SGR – SNR

1. Introduction

In this work, we examine the connections of anomalous X-ray pulsars (AXPs) (see van Kerkwijk 2000 and Mereghetti 2001a, 2001b for reviews) and soft gamma repeaters (SGRs) (see Hurley 2000 for a review) with supernova remnants (SNRs).

These two classes of objects have attracted much attention. The SGRs exhibit repeated bursts of soft gamma rays. Their quiescent X-ray properties are similar to those of AXPs. Indeed, AXPs and SGRs together constitute the set of all neutron stars with typical accretion luminosities, observed rotation periods but without evidence for binary companions. Both classes of objects are similar in their periods (P $\sim$ 10 s), period derivatives, spectra, and luminosities.

There are currently two alternative models for these objects. The magnetar model posits that these sources are isolated rotating neutron stars with surface dipole magnetic fields of 10^{14}-10^{15} G, extracting their luminosity from the decay of the magnetic field. The magnetar picture also provides a model for the soft gamma-ray bursts. The spindown of the object is believed to obey a modified dipole spindown equation, $\dot{\Omega} = -k\Omega^n$ where n = 3 for pure dipole radiation, and n can be greater than 3, possibly as high as n = 5 when the decay of the magnetic field is driven by spindown (Ruderman et al., 1998). In magnetar models the age of the neutron star can be estimated as a characteristic time $\tau = P/(n-1)\dot{P}$, assuming that the initial rotation period was much shorter than the current rotation period.

The alternative model is that the X-ray luminosity is due to accretion from a fall-back disk that is left over from the supernova that formed the neutron star. This model does not include a dynamical explanation for the gamma-ray bursts of the SGRs. It seeks to classify all kinds of young neutron stars as propellers and accretors from a fall-back disk. The similarities and differences of the different classes, including the radio pulsars, the dim thermal neutron stars, and the "radio quiet" neutron stars like the source in Cas A in addition to the AXPs and perhaps SGRs, are supposed to be due to the presence or absence of a fall-back disk and different disk initial conditions. In this model AXPs and SGRs are supposed to be in an asymptotic regime near rotational equilibrium, and there is no way to estimate their ages from the observed period, P and period derivative, $\dot{\rm P}$. Therefore, for discussing the possible association of AXPs and SGRs with SNRs, age information for the SNR can be used to make a comparison only if it is assumed that the AXP or SGR is a magnetar.

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Finding genetic relations between AXPs/SGRs and SNRs is important for several reasons. We have much more information about SNRs than we do for AXPs/SGRs. If we find a genetic connection between an AXP/SGR and a SNR we can use the SNR's data for the AXP/SGR. In particular the age of the SNR can be used to provide an age estimate for the AXP/SGR within error limits. It is also important to find distances of AXPs/SGRs. By using the distance value of the associated SNR as the distance of the AXP/SGR we can calculate the luminosity of such objects. Further, it is important to compare the characteristics of the SNRs possibly connected with AXPs/SGRs with the characteristics of other SNRs associated with radio pulsars to see if there are significant differences between them.

Some of the young radio pulsars are not associated with SNRs; Kaspi (2000) gives a list of the youngest 17 pulsars with "characteristic ages" $\tau = \mathrm{P}/2\dot{\mathrm{P}} \leq 2.44 \times 10^4$ yrs. For 7 of these pulsars genetic relations with SNRs were not found. It can therefore be inferred that some SNRs have very short lifetimes. Therefore, failing to find SNRs around AXPs and SGRs does not necessarily mean that AXPs and SGRs have to be much older than 10^4-10^5 yrs, the lifetime of SNRs.

There are several criteria to be checked to see if there is a genetic connection between an X-ray pulsar and a SNR (see Kaspi 2000 and Allakhverdiev et al. 1997a for pulsar - SNR connections). One must try to use all of these criteria to check if the connection is real or not, taking into account the reliability and applicability of each of the criteria. Some important points to be checked for an association to be real are: 1) Position of the neutron star with respect to the geometrical center of the SNR. 2) Evidence for interactions between the neutron star and the ambient medium. 3) Comparing neutral hydrogen column density ($\mathrm{N_{HI}}$) values of the neutron star and the SNR within error limits to check if they can be at the same distance. 4) Comparing the estimated space velocities of AXPs/SGRs with the space velocity distribution of radio pulsars. The velocity estimates in our Tables refer to the projected space velocity on the sky and, on the average, space velocity is $(3/2)^{1/2}$ times the projected space velocity. 5) Comparing the age of the SNR and the characteristic time, $\tau = P/(n-1)\dot{P}$ of the AXP/SGR is relevant for assessing the possibility that these sources are magnetars. The characteristic time taken as τ is close to the real age only if the neutron star is an isolated rotating dipole and if its period is much greater than its initial period. If AXPs and SGRs are magnetars then, due to magnetic field decay and/or interaction with the surrounding matter, a characteristic age $\tau = P/(n-1)\dot{P}$, $\mathrm{n} \neq 3$, may give a close estimate of the real age. The comparison of the neutron star age with the SNR age is model dependent but possible for a range of magnetar/field-decay models. If AXPs and SGRs are accreting sources, then $\tau = P/(n-1)\dot{P}$ is not related with the real age.

Among these criteria the strongest one is the position of the AXP/SGR with respect to the SNR. Because AXPs and SGRs are rare objects, chance projection is not very probable. The data related with the other criteria are usually insufficient and not very reliable. As the observational data improve, the criteria other than the position will become more usable. Our strategy is to take all criteria into account while examining the connections, keeping in mind the uncertainties of each criterion. The dynamical characteristics of the shells of the SNRs possibly connected with the AXPs/SGRs are, in general, similar to the characteristics of the radio pulsar associated SNR shells. We therefore assume, for our discussion of space velocities, that AXPs/SGRs have roughly the same kinematical characteristics as the radio pulsars.

In a companion paper we attempt to improve the distance values of the SNRs given in the Galactic SNRs catalog (Green, 2000) by examining the distance values of the SNRs given in the literature, their neutral hydrogen column densities ($\mathrm{N_{HI}}$), explosion energies (E) of the supernovae that formed them, and densities of the ambient medium (Ankay et al., 2001). The distance and the diameter values presented without giving references in Tables 2 and 4 were taken from this work.

In Section 2, we discuss possible connections of SGRs and AXPs to SNRs. For AXP/SNR associations our conclusions weighing all available criteria agree with the conclusions of Gaensler et al. (2001) on the basis of positional coincidence alone. For SGR/SNR associations, we conclude that several connections previously excluded by Gaensler et al. (2001) are actually likely. Marsden et al. (2001) also examined possible connections for the group of AXPs and SGRs we investigate here. In addition, they study the sources AXP 0720-3125 and SGR 1801-23 which are not confirmed as AXP and SGR, respectively. These two sources are not considered here. They conclude almost all of the AXPs/SGRs, and the unconfirmed AXP/SGR candidates they study are associated with SNRs, leading in some cases to very high neutron star space velocities with realistic distances. These associations were adopted without comparative study of different criteria. We conclude that only 3 AXP-SNR associations and 2 SGR-SNR associations can be adopted with some confidence. We present the conclusions in Section 3.

2. Connections of AXPs and SGRs with SNRs

Below, we examine each pair of AXP/SGR-SNR using the data of AXPs/SGRs and SNRs given in Tables 1,3 and 2,4, respectively. In the Tables, $\beta \equiv \Delta\theta/\theta$ is the ratio between the offset, $\Delta\theta$, of the neutron star's position from the geometrical center of the SNR and the angular radius, θ, of the SNR. By this definition, $\Delta\theta/\theta$ corresponds to $\mathrm{V_{NS}}/\mathrm{V_{exp}}$, where $\mathrm{V_{NS}}$ denotes the projected space velocity of the neutron star and $\mathrm{V_{exp}}$ denotes the expansion velocity of the SNR.

Table 1. The Data of Soft-gamma Repeaters

Names & Remarks	P (s)	$\dot{P}10^{-11}$ (ss^{-1})	$\tau 10^3$ (yr)	d (kpc)	$N_{HI}10^{21}$ (cm^{-2}) ($0.1-2.4$keV)
SGR 0526-66	8.1			$50-55$	$5-10$
SNR N49	[6]				[7]
Connection					
SGR 1806-20	7.47	8.3	1.4	14.5	60
(AX 1805.7-2025)	[1]	[1]		[15]	[1, 10, 12]
SNR G10.0-0.3		$8.1-11.7$			
Jet		[9]			
[14, 13]					
Connection					
SGR 1900+14	5.16	11	$0.74-1.3$	5	21.6
SNR G42.8+0.6	[2, 3, 8, 13]	[2]	0.71	[3]	[3]
		5.82	[3]		$\sim 30-50$
		[4]			[2]
		6.0			
		[13, 10]			
		6.13			
		[8]			
SGR 1627-41	6.41?			11	77
SNR G337.0-0.1	[4, 5]			[11]	[4]
(CTB 33)					

[1] Kouveliotou et al., 1998; [2] Kouveliotou et al., 1999; [3] Hurley et al., 1999b; [4] Woods et al., 1999a; [5] Dieters et al., 1998; [6]Mazets et al., 1979; [7] Marsden et al., 1996; [8] Woods et al., 1999b; [9] Woods et al., 2000; [10] Sonobe et al., 1994; [11] Corbel et al., 1999; [12] Murakami et al., 1994; [13] Marsden et al., 1999; [14] Kulkarni et al., 1994; [15] Green, 2000

2.1. SGR-SNR Connections

SGR 0526-66 – SNR N49: The position of SGR 0526-66 is close to the boundary of SNR N49 in the Large Magellanic Cloud. The SNR is expanding roughly spherically in a medium in which there are many dense clouds. Its surface brightness values are very inhomogeneous in both radio and X-ray bands (Banas et al., 1997; Williams et al., 1999; Castro-Tirado & Gorosabel, 1999). As the linear diameter of the SNR is about 15-16 pc its age should not be much larger than t = 5.5×10^3 yrs (Vancura et al., 1992). Taking the age of the SGR to be 5.5×10^3 yrs the space velocity of the neutron star must be approximately 1200 km/s (Marsden et al., 1999). No bow-shock or jet from the SGR has been observed. For comparison, PSR J1801-2451 associated with SNR G5.4-1.2, which has the largest β value (close to 1) among all of the radio pulsars connected with SNRs and a comparable high velocity, does show a bow-shock (Frail and Kulkarni, 1991).

N49 has a large and thermal luminosity in the ultraviolet and X-ray bands (Hughes et al., 1998; Banas et al., 1997). This is the result of the ambient medium being very dense. The explosion energy of N49 is $\sim 1.5 \times 10^{51}$ ergs but, as it is expanding in a dense medium, its expansion velocity must have dropped rapidly. Even with the large SGR velocity, the observed β = 0.6-1 indicates that the SNR has expanded at a low rate, of the order of the pulsar's velocity. From the range β = 0.6-1, V = 1000-1700 km/s, we adopt a representative value, V_{NS} = 1200 km/s (Marsden et al., 1999). According to Allakhverdiev et al. (1997b) the space velocity distribution of pulsars has a mean $\bar{V}_{NS} \cong 250$ km/s. Hansen & Phinney (1997) give $\bar{V}_{NS} \cong$ 250-300 km/s with a standard deviation σ = 190 km/s. On the other hand, Lorimer et al. (1997) give a higher value $\bar{V}_{NS} \cong 500$ km/s. Although V_{NS} = 1200 km/s for SGR 0526-66 is $\sim$ 2.5-5 times higher than these mean pulsar velocity values, this velocity value is compatible with the high velocity tail of the space velocity distribution of pulsars, which extends to roughly 1000 km/s.

The N_{HI} values of the SGR and the SNR are comparable within error limits and based on the positional coincidence we conclude that this association is real. The association will be definitely confirmed if future observations resolve a bow-shock or jet from SGR 0526-66.

SGR 1806-20 – SNR G10.0-0.3: SGR 1806-20, with $\beta \leq 0.5$ as seen from Table 2, is projected relatively close to the center of SNR G10.0-0.3. The SNR's angular dimensions are $6' \times 9'$ (Frail et al., 1997), so that its linear diameter must be $\sim$ 24 pc if its distance is $\sim$ 11 kpc consistent with $N_{HI} = 6 \times 10^{22}$ cm^{-2}. On the other hand, as the X-ray surface brightness is concentrated in the central part of the SNR (plerion type, Vasisht et al., 1995; in

Table 2. The Data of Supernova Remnants in the Directions of SGRs

Names & Remarks	d (kpc)	t (kyr)	E_{kin} $(10^{50} erg)$	kT (keV)	$Type$	α	$\Delta\theta/\theta$ $(or \beta)$	D (pc)	N_{HI} $(10^{21} cm^{-2})$	L_X $(10^{33} erg/s)$	$Density$ $(\sharp/cm^3)$	V_{NS} (km/s)
N49	$50-55$	5.5	~ 15	0.6	$S?$		$0.6-1$	16	21	63^{a}	$n_o = 30^{c}$	1200^{e}
(in LMC)		[8, 11, 15]	[15]	[15]			[8]	[8]	[15]	[15]	[14, 8]	[11]
							0.8			2100^{b}	$n_o = 2.6^{c}$	2900
							[11]			[13]	[15]	[10]
											$20-940^{d}$	
											[13]	
G10.0-0.3	12	10			?	0.8	$0.0-0.5$	24			$Dense$	800
	11	[11]			F	[18]	0.5				$Maser$	[11]
	[9]				[6]	0.6	[11]				[1]	
	14.5					[6]						
	[17]											
G42.8+0.6	6	10			S	0.5?	$1.2-1.4$	42		^{f}	Not	~ 1800
	5	[6, 10, 11]				[18]	[10]			[7]	$Dense$	[10]
	[7]						1.4					2000
							[11]					[11]
												$480-5500$
												[5]
G337.0-0.1	12	~ 5			S	0.6?	$2-2.3$	6			$Dense?$	800
(CTB 33)	11	[9]				[18]	[9]	4.8			$Masers$	[10]
	[9, 4]						1.6	[9]			[12, 1, 9, 2]	1000
							[3]	5.1				[11, 9]
							1.7	[4]				$200-2000$
							[16]					[16]

[1] Frail et al., 1996; [2] Brogan et al., 2000; [3] Smith et al., 1999; [4] Sarma et al., 1997; [5] Hurley et al., 1999b; [6] Vasisht et al., 1995; [7] Vasisht et al., 1994; [8] Vancura et al., 1992; [9] Corbel et al., 1999; [10] Gaensler, 2000; [11] Marsden et al., 1999; [12] Koralesky et al., 1998b; [13] Banas et al., 1997; [14] Blair et al., 2000; [15] Hughes et al., 1998; [16] Hurley et al., 1999a; [17] Green, 2000

[a] for 0.5-5 keV
[b] optical
[c] preshock
[d] clouds
[e] adopted in the present assessment
[f] no other SNR with L_X>0.001 erg/s

Green, 2000, where SNRs are classified according to radio data only, the type of this remnant is not determined) we can assume that this SNR is C-type. The corresponding excess in the radio band is not resolved in current data. Sometimes a jet is observed in the plerionic part of the SNR (Frail et al., 1997).

In Green (2000) the SNR's spectral index is $\alpha = 0.8$ and in Vasisht et al. (1995) it is given as $\alpha = 0.6$. For an S- or C-type remnant with an age of 10^4 yrs (Marsden et al., 1999) $\alpha = 0.6$ is a reasonable value.

Even if we assume that there is an uncertainty of a factor of about 2 in the SNR's age the characteristic age of SGR 1806-20 is at least 3.5 times less than the age of SNR G10.0-0.3 which corresponds to a braking index of 1.6. Although young radio pulsars have braking index values less than 3 none of them has n < 2, except for the Vela pulsar for which n = 1.4 was claimed (Lyne et al. 1996), but this is subject to some uncertainty because of the large effects of interglitch relaxation in this pulsar.

Based on the positional coincidence and the observed jet in addition to the plerionic characteristic of the SNR, there seems to be a genetic connection between SGR 1806-20 and SNR G10.0-0.3.

SGR 1900+14 – SNR G42.8+0.6: SGR 1900+14, as seen from Table 2, is located outside SNR 42.8+0.6 (see also Hurley et al., 1999b). There is a high mass X-ray binary (HMXB 1907+0.97) in this direction ($l = 43.7^o$, $b = 0.5^o$) with $N_{HI} \cong 1.5 \times 10^{22}$ cm^{-2} and distance ~ 3 kpc (Guseinov et al., 2000, 2001). N_{HI} value of SGR 1900+14 is $\sim 3 \times 10^{22}$ cm^{-2}, suggesting that it may be located in the Sagittarius arm of the Galaxy, 6 kpc from the Sun. The distance of the SNR is given as 5 kpc (Vasisht et

Table 3. The Data of Anomalous X-ray Pulsars

Names & Remarks	P (s)	$\dot{P}10^{-11}$ (ss^{-1})	$\tau 10^3$ (yr)	d (kpc)	$N_{HI}10^{21}$ (cm^{-2}) ($0.1-2.4$keV)
AXP 1E 1841-045	11.77	4.1	4.7	$6-7.5$	30
SNR G27.4+0.0	[11, 12]	[12]		[16]	[13]
(Kes 73)					
Connection					
AXP AX J1845.0-0300	6.97	0.78?	14?	~ 8.5	46
(AX J1845-0258)	[14]			[14, 18]	[13]
SNR G29.6+0.1				15	100
Connection				[2]	[18, 19]
AXP 1E 2259+586	6.98	0.06	180	5.6	8.5
SNR G109.1-1.0	[7, 5, 19]	[5, 8, 19]		[17]	[6]
(CTB 109)					9
Jet [19]					[13]
Connection					$3-12$
					[20]
AXP RXS J170849-4009	11.0	2.25	8.7		14
SNR G346.6-0.2	[9]	[10]			[13, 9]
AXP 1E 1048.1-5937	6.45	$1.5-4$	$2.5-6.7$	$> 2.8, 10$	$5.5-16$
SNR G287.7-0.5	[2, 1]	[3, 4]		[2]	[1]
(absent in Green, 2000)		3.3	3.7	10.6	5
		[1]		[15]	[13]
				3	
				[1]	

[1] Corbet & Mihara, 1997; [2] Seward et al., 1986; [3] Mereghetti, 1995; [4] Oosterbroek et al., 1998; [5] Baykal & Swank, 1996; [6] Rho & Petre, 1997; [7] Fahlman & Gregory, 1981; [8] Kaspi et al., 1999; [9] Sugizaki et al., 1997; [10] Israel et al., 1999; [11] Vasisht & Gotthelf, 1997; [12] Gotthelf et al., 1999; [13] Mereghetti, 2001a; [14] Torii et al., 1998; [15] Mereghetti & Stella, 1995; [16] Sanbonmatsu & Helfand, 1992; [17] Hughes et al., 1984; [18] Gaensler et al., 1999; [19] Morini et al., 1988; [20] Parmar et al., 1998

al., 1994) and 6 kpc (Ankay et al., 2001) consistent with the distance of the Sagittarius arm. $\dot{P}$ values of the SGR vary considerably with time. An average characteristic age value, $\tau = P/2\dot{P}$, of 10^3 yrs can be adopted for this SGR. This value is 10 times less than the age of the SNR. As the relevance of the characteristic age to real age depends on the theoretical model, we must turn to other criteria before ruling out this association. If we assume the age of the SGR to be as large as the SNR's age, i.e. 10^4 yrs, and if its distance is 6 kpc, projection of its space velocity on the sky is (2-3) $\times$ 10^3 km/s, depending on the estimation of β. These velocities are $\sim$ 4-12 times larger than average pulsar velocity values given above (Allakhverdiev et al., 1997b; Hansen & Phinney, 1997; Lorimer et al., 1997). In addition, $\beta > 1$. Last but not least, Lorimer & Xilouris (2000) have discovered a young radio pulsar, PSR J1907+0918, of period 226 ms, which is the likely true association of SNR G42.8+0.6. Because of these reasons, we conclude that there is not a genetic relation between SGR 1900+14 and SNR 42.8+0.6. It should also be noted that in the direction of the SGR no SNR with $L_X > 10^{32}$ ergs/s was found in the X-ray band (Vasisht et al., 1994).

SGR 1627-41 – SNR G337.0-0.1 (CTB 33): SGR 1627-41 is located outside SNR G337.0-0.1 (CTB 33) (see Table 2). These two objects may be approximately at the same distance. If the SNR's progenitor was an O-type star (we may assume this to be true, because the medium surrounding the SNR is very dense), then the SNR is expanding within an HII region. Within the HII region there may be some dense clouds (the SNR has an irregular shape). The neutron star velocity values presented in Table 2 were calculated assuming the SNR's age to be 5 $\times$ 10^3 yrs. As seen from Table 2, for β = 2-2.3 the projection of the space velocity of the neutron star is 800-1000 km/s. In this case, average velocity of the SNR's shock wave must be about 500 km/s or less. If such a young SNR's expansion velocity were < 500 km/s then the supernova explosion energy should be relatively low. Could the neutron star velocity be 2-4 times greater than the average velocity of pulsars if the supernova explosion energy were really low? This might be the case only if the supernova explosion energy was very asymmetric.

There seems to be another contradiction concerning the SNR alone: An age of t $\sim$ 5000 years is a large value for D = 5-6 pc. As the linear diameter value cannot be very different from 5-6 pc, the age of the SNR might be even less

Table 4. The Data of Supernova Remnants in the Directions of AXPs

Names & Remarks	d (kpc)	t (kyr)	$E_{\rm kin}$ ($10^{50} erg$)	kT (keV)	$Type$	α	$\Delta\theta/\theta$ ($or \beta$)	D (pc)	$N_{\rm HI}$ ($10^{21} cm^{-2}$)	$L_{\rm X}$ ($10^{33} erg/s$)	$Density$ ($\sharp/cm^3$)	$V_{\rm NS}$ (km/s)
G27.4+0.0	6.5	≤ 3		~ 0.86	S	0.68	$0.1-0.2$	7.6	5	200[b]	$Dense?$	< 500
(Kes 73)	[5]	[5, 6]		[6]		[16]	[5, 7]		[5]	[5]		[9]
[7]		2					0.1		$5-20$			200
		[7]					[10]		[6]			[10]
G29.6+0.1	11	< 8			S	0.5?	$0.1-0.2$	16				< 500
[1]	12	[1, 2]				[16]	[1]					[9]
	[10]	10				$0.4-0.7$	0.1					200
		[10]				[1]	[10]					[10]
G109.1-1.0	5	3	$10-100$	0.95	S	0.50	$0.2-0.3$	40.6	4	~ 1000[c]	$D.M.C.$[f]	< 500
(CTB 109)	$3.6-5.2$	[3, 4]	[14]	[4]		[16]	[3, 8]		[14]	~ 40[d]	[4, 16]	[9]
X-ray jet[a]	[15]	10		0.7			0.2		$8-10$	[14]	$\bar{n_{\rm O}} = 0.25$	~ 300[h]
[14]		[14, 3, 8]		[14]			[10]		[12]	$120 d_{3.5}^2$[e]	[14]	[10]
		$12-17$									$n_{\rm O} = 20$[g]	15[i]
		[15]									[11]	
G346.6-0.2	10	20			S	0.5?	≥ 1.7	23			$Dense?$	1000
	$9-10$	[10]				[16]	[10]				$Maser$	[10]
	[10]										[13]	

[1] Gaensler et al., 1999; [2] Gotthelf et al., 2000; [3] Rho & Petre, 1997; [4] Parmar et al., 1998; [5] Sanbonmatsu & Helfand, 1992; [6] Helfand et al., 1994; [7] Vasisht & Gotthelf, 1997; [8] Green, 1989; [9] Gaensler, 2000; [10] Marsden et al., 1999; [11] Fesen & Hurford, 1995; [12] Rho & Petre, 1993; [13] Koralesky et al., 1998a; [14] Morini et al., 1988; [15] Gregory & Fahlman, 1980; [16] Green, 2000

[a] with kT≈0.3 keV
[b] for 0.3-4 keV
[c] for >0.1 keV
[d] for >2 keV
[e] for 1.2-20 keV
[f] dense molecular cloud
[g] preshock
[h] for t=(7-10) × 10^3 yrs
[i] for t=1.8 × 10^5 yrs

than 5000 years. In this case, the projected space velocity of the neutron star becomes > 1000 km/s, making the discrepancy between the neutron star kinetic energy and the supernova explosion energy even stronger. In addition to these difficulties, β = 1.6-2.3, i.e. the neutron star is well outside the remnant. A genetic connection between SGR 1627-41 and SNR G337.0-0.1 is unlikely.

2.2. AXP-SNR Connections

AXP 1E 1841-045 – SNR G27.4+0.0: AXP 1E 1841-045 is projected on the central region of SNR G27.4+0.0 (see Table 4). It is seen from Tables 3 and 4 that the $N_{\rm HI}$ value of the AXP is about 3 times greater than the SNR's neutral hydrogen column density. If we take into account the uncertainty in $N_{\rm HI}$ values we cannot exclude the possibility of a connection between the AXP and the SNR. If the AXP is a magnetar, the characteristic age of the AXP is 4.7 × 10^3 yrs. The age of the SNR is estimated as (2-3) × 10^3 yrs. Considering the uncertainties in the ages of the AXP and the SNR we can assume that both have ages of about (3-5) × 10^3 yrs. This is not a bad assumption, because the implied space velocity of the AXP is < 500 km/s (Table 4, last column). So, AXP 1E 1841-045 might be born in the same supernova explosion that formed the SNR G27.4+0.0 which is considered to be an S-type SNR (Green, 2000).

On the basis of the central position of AXP 1E 1841-045 within SNR G27.4+0.0 and the compatibility of distance values, we conclude this is a true association. The ages are also consistent if the AXP is a magnetar.

AXP J1845.0-0300 – SNR G29.6+0.1: AXP J1845.0-0300 is projected on the center of SNR G29.6+0.1. This AXP has an $N_{\rm HI}$ value of ∼ (5-10) × 10^{22} cm^{-2}. SNR G29.6+0.1 is at ∼ 11 kpc and has a direction of l ∼ 30$^{\rm o}$, so that, the line of sight cuts the Sagitarius arm of the Galaxy twice and the Expanding arm, which is 3 kpc away from the Galactic center, once. So, the $N_{\rm HI}$ value of the

SNR can also be large, possibly of the order of the AXP's N_{HI}. For such high N_{HI} values it is not possible to test distance agreement to better than 2-3 kpc. Thus, we can not exclude the possibility of a connection between the AXP and the SNR, because the AXP is projected on the center of SNR G29.6+0.1. SNR G29.6+0.1 has not yet been investigated in detail. There may be structure in the central region of this remnant. If resolved this would constitute supportive evidence for the association. We conclude that a genetic connection between AXP J1845.0-0300 and SNR G29.6+0.1 is likely.

AXP 1E 2259+586 – SNR G109.1-1.0 (CTB 109): AXP 1E 2259+586, as seen from Tables 3 and 4, must have a genetic relation with SNR G109.1-1.0 (CTB 109) (see β, d, N_{HI} values). This SNR is S-type in both radio and X-ray bands. In this region of the Galaxy, in the anticenter direction, it is particularly improbable for an AXP to have a projection on the central region of a SNR by chance. As evidence for connection, X-ray observations show a jet in CTB 109 (Morini et al., 1988).

Contrary to these indications of a connection, if the AXP is a magnetar the SNR's age of about (3-10) $\times$ 10^3 yrs does not agree with the AXP's characteristic time $P/2\dot{P}$ = 1.8 $\times$ 10^5 yrs (for n = 3). As known from different evolutionary tracks of pulsars on the P-$\dot{P}$ diagram the braking index (n) of a pulsar which is expected to have a very high magnetic field and has a luminosity of about 10^{35} ergs/s in the X-ray band may be ≤ 3 because of the interaction of the pulsar with the surrounding matter (Yusifov et al. 1995). But, in this case the difference between the ages becomes even larger. Even if we assume that the AXP is a magnetar with significant field decay, and the SNR's age has an uncertainty of a factor of ~ 2, an average braking index n $\geq$ 13 is obtained. For such power law decay, or exponential decays of the magnetic field, we might expect to see evidence of the energy released, since magnetar fields are supposed to be responsible for the bursts in SGRs. There is no evidence of an extra energy source in the properties of AXP 1E 2259+586 and SNR CTB 109.

It is highly probable that there is a genetic relation between AXP 1E 2259+586 and SNR G109.1-1.0 on the basis of the significant positional coincidence and distance. In this case, there is a strong age discrepancy for the magnetar model.

AXP RXS J170849-4009 – SNR G346.6-0.2: For this AXP – SNR pair, the value of $\beta \geq 1.7$ is large. If the distance of the AXP is 10 kpc and its age is 2 $\times$ 10^4 yrs, the same as the SNR's age, projection of its space velocity on the sky will be 1000 km/s. If the angular diameter of the SNR is $8'$ (Green 2000) then, from the Σ-D relation, its diameter and distance will be 23 pc and 10 kpc, respectively (Ankay, 2001). At 10 kpc the AXP would be beyond the Inner (Expanding) arm of the Galaxy. The N_{HI} value is consistent with such a location. Although distance and N_{HI} values are compatible, β is so large, and the velocity inferred is also large compared to the velocities inferred for the other AXPs. We conclude that there is no connection between the AXP and the SNR.

AXP 1E 1048.1-5937 – G287.8-0.5: There is no candidate SNR that can be genetically related with AXP 1E 1048.1-5937. In the direction of this AXP there is the source G287.8-0.5 which was given as an unexamined SNR candidate (Jones, 1973; Becker et al., 1976), but it is not included in the Galactic SNRs catalog of Green (2000). As the data of this source are insufficient and not reliable it is difficult to claim it as a SNR and it does not make much sense to examine its possible relation with the AXP.

AXP 4U 0142+61: There is no SNR observed in this direction.

3. Conclusions

We found that 3 AXPs and 2 SGRs are, most probably, genetically connected with related SNRs: AXP 1E 1841-045 – SNR G27.4+0.0 (Kes 73), AXP AXJ 1845.0-0300 – SNR G29.6+0.1, AXP 1E 2259+586 – SNR G109.1-1.0 (CTB 109), SGR 0526-66 – SNR N49, SGR 1806-20 – SNR G10.0-0.3.

The difference between the age of the SNR and the characteristic time of the AXP/SGR is very large in two cases even if we take into account the uncertainty in the age of the SNR which is about a factor of 2. For the pair AXP 1E 2259+586 – SNR G109.1-1.0 (CTB 109) the τ value of the AXP is at least 6 times greater than the age of the SNR. So, the braking index of AXP 1E 2259+586 must be at least 13. In the case of SGR 1806-20 – SNR G10.0-0.3 the situation is just the opposite; the age of the SNR is at least 3.5 times greater than the τ value of the SGR which corresponds to a braking index value of about 1.6. For the other two associated AXP-SNR pairs, the τ and SNR age values are comparable within error limits. These characteristic ages are relevant to magnetar models. The associations then indicate that, if the AXPs and SGRs are magnetars then not all AXPs and SGRs are the same kind of magnetar. Furthermore, if the supposed magnetar age is as small as the SNR age, as in the case of AXP 1E 2259+586, then the rate of energy release by the magnetic field is very large. The question is then why there is no evidence of this energy release either in the SNR or in some signature of the AXP.

SGR 0526-66 and SGR 1806-20, which are associated with SNRs, have projected space velocities $V_{NS} \sim$ 800-1200 km/s, higher than the average space velocity of pulsars but consistent with the high velocity tail of the radio pulsar space velocity distribution. The AXPs connected with SNRs have projected space velocities < 500 km/s consistent with the average space velocity of pulsars. We note that the velocity values given in Tables 2 and 4 refer to the projected space velocity on the sky and, on the average, the space velocity is equal to $(3/2)^{1/2}$ times the projected space velocity.

The SNRs connected with the SGRs are not normal S-type remnants, whereas the SNRs connected with the AXPs are pure S-type. Similar to the effects of radio pulsars connected with SNRs, the effects of SGRs on their re-

lated SNRs are stronger compared to the effects of AXPs. For pulsars the source of such effects on SNRs is the loss of the neutron star's rotational energy, i.e. $\dot{E} = 4\pi^2 \mathrm{I}(\dot{P}/P^3)$. For the effect on the SNR to be large $\dot{E}$ must be large. $\dot{E}$ values of AXPs and SGRs are about 10^2-10^3 times less than the $\dot{E}$ values of young pulsars. Because of this, the SNRs genetically related with AXPs and SGRs being S-type would be considered normal if rotational energy were the only energy source. If AXPs and SGRs are the same type of object, and if they have energy sources other than rotation, either for accretion or for magnetar models, why is it that the SNRs associated with SGRs are different from the SNRs associated with AXPs? In particular, if AXPs also experience gamma-ray bursts powered by magnetic energy, then why is it that the SNRs associated with AXPs do not contain plerions?Are the differences in the SNR morphologies significant, since we have only five SNRs associated with AXPs and SGRs? These issues may be resolved with better resolution images of the SNRs.

We investigated the medium in which the AXPs, SGRs, and pulsars (genetically related with the SNRs) are located in to find possible masses of the progenitors through associated star clusters and to check if there are some differences in density of the ambient medium. Contrary to the claim of Marsden et al. (2001), we did not find any significant differences in the density of the SNRs connected with AXPs/SGRs compared to the density of the SNRs associated with radio pulsars located in Galactic arm regions (see Tables 2 and 4).

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References

Allakhverdiev, A. O., Alpar, M. A., Gök, F. & Guseinov, O. H. 1997a, Turkish J. of Phys., 21, 688
Allakhverdiev, A. O., Guseinov, O. H., Tagieva, S. O. & Yusifov, I. M. 1997b, ARep, 41, 257
Ankay, A., Guseinov, O. H., Tagieva, S. O. & Sezer, A. 2001, to be submitted
Banas, K. R., Hughes, J. P., Bronfman, L. & Nyman, L. -A 1997, ApJ, 480, 607
Baykal, A. & Swank, J. 1996, ApJ, 460, 470
Becker, R. H., Boldt, E. A., Holt, S. S., et al. 1976, ApJ, 209, L65
Blair, W. P., Sankrit, R., Shelton, R., et al. 2000, ApJ, 538, L61
Braun, R., Goss, W. M. & Lyne, A. G. 1989, ApJ, 340, 355
Brogan, C. L., Frail, D. A., Goss, W. M. & Troland, T. H. 2000, ApJ, 537, 875
Castro-Tirado, A. J. & Gorosabel, J. 1999, A&A, 341, 487
Corbel, S., Chapuis, C., Dame, T. M. & Durouchoux, P. 1999, ApJ, 526, L29
Corbet, R. H. D. & Mihara, T. 1997, ApJ, 475, L127
Dieters, S., Woods, P., Kouveliotou, C. & van Paradijs, J. 1998, IAU Circ., 6962
Fahlman, G. G. & Gregory, P. C. 1981, Nature, 293, 202
Fesen, R. A. & Hurford, A. P. 1995, AJ, 110, 747
Frail, D. A., Goss, W. M., Reynoso, E. M., et al. 1996, AJ, 111, 1651
Frail, D. A. & Kulkarni, S. R. 1991, Nature, 352, 785
Frail, D. A., Vasisht, G. & Kulkarni, S. R. 1997, ApJ, 480, L129
Gaensler, B. M., Gotthelf, E. V. & Vasisht, G. 1999, ApJ, 526, L37
Gaensler, B. M. 2000, Pulsar Astronomy - 2000 and Beyond, ASP Conference Series, edited by M. Kramer, N. Wex & R. Wielebinski, Vol.202, p.703
Gaensler, B. M., Slane, P. D., Gotthelf, E. V. & Vasisht, G. 2001, astro-ph/0104228
Gotthelf, E. V., Vasisht, G. & Dotani, T. 1999, ApJ, 522, L49
Gotthelf, E. V., Vasisht, G., Gaensler, B. M. & Torii, K. 2000, Pulsar Astronomy - 2000 and Beyond, ASP Conference Series, edited by M. Kramer, N. Wex & R. Wielebinski, Vol.202, p.707
Green, D. A. 1989, MNRAS, 238, 737
Green, D. A. 2000, 'A Catalogue of Galactic Supernova Remnants (2000 August version)', http://www.nrao.cam.ac.uk/surveys/snrs/
Gregory, P. C. & Fahlman, G. G. 1980, Nature, 287, 805
Guseinov, O. H., Saygaç, A. T., Allakhverdiev, A., et al. 2000, AstL, 26, 725
Guseinov, O. H., Yerli, S. K., Tagieva, S. O. & Ankay, A. 2001, to be submitted
Hansen, B. M. S. & Phinney, E. S. 1997, MNRAS, 291, 569
Helfand, D. J., Becker, R. H., Hawkins, G. & White, R. L. 1994, ApJ, 434, 627
Hughes, J. P., Helfand, D. J. & Kahn, S. M. 1984, ApJ, 281, L25
Hughes, J. P., Hayashi, I. & Koyama, K. 1998, ApJ, 505, 732
Hurley, K., Kouveliotou, C., Woods, P., et al. 1999a, ApJ, 510, L107
Hurley, K., Li, P., Kouveliotou, C., et al. 1999b, ApJ, 510, L111
Hurley, K. 2000, The Fifth Compton Symposium, edited by M. L. McConnell and J. M. Ryan, AIP Conference Proceedings, Vol.510, p.515, astro-ph/9912061
Israel, G. L., Covino, S., Stella, L., et al. 1999, ApJ, 518, L107
Jones, B. B. 1973, Australian J. Phys., 26, 545
Kaspi, V. M., Chakrabarty, D. & Steinberger, J. 1999, ApJ, 525, L33
Kaspi, V. M. 2000, Pulsar Astronomy – 2000 and Beyond, ASP Conference Series, edited by M. Kramer, N. Wex & R. Wielebinski, vol.202, p.485, astro-ph/9912284
Koralesky, B., Frail, D. A., Goss, W. M., Claussen, M. J. & Green, A. J. 1998a, AJ, 116, 1323
Koralesky, B., Rudnick, L., Gotthelf, E. V. & Keohane, J. W. 1998b, ApJ, 505, L27
Kouveliotou, C., Dieters,S., Strohmayer, T., et al. 1998, Nature, 393, 235
Kouveliotou, C., Strohmayer, T., Hurley, K., et al. 1999, ApJ, 510, L115
Kulkarni, S. R., Frail, D. A., Kassim, N. E., Murakami, T. & Vasisht, G. 1994, Nature, 368, 129
Lorimer, D. R., Bailes, M. & Harrison, P. A. 1997, MNRAS, 289, 592
Lorimer, D. R. & Xilouris, K. M. 2000, ApJ, 545, 385
Lyne, A. G., Pritchard, R. S., Graham-Smith, F. & Camilo, F. 1996, Nature, 381, 497
Marsden, D., Lingenfelter, R., Rothschild, R. & Higdon, J. 1999, American Astronomical Society Meeting, 195, 26.05

Marsden, D., Rothschild, R., Lingenfelter, R. & Puetter, R. C. 1996, ApJ, 470, 513
Marsden, D., Lingenfelter, R. E., Rothschild, R. E. & Higdon, J. C. 2001, ApJ, 550, 397
Mazets, E. P., Golentskii, S. V., Ilinskii, V. N., Aptekar, R. L. & Guryan, Iu, A. 1979, Nature, 282, 587
Mereghetti, S. 1995, ApJ, 455, 598
Mereghetti, S. & Stella, L. 1995, ApJ, 442, 417
Mereghetti, S. 2001a, Invited Talk presented at the Workshop Frontier Objects in Astrophysics and Particle Physics, Vulcano (Italy), astro-ph/0102017
Mereghetti, S. 2001b, NATO ASI on The Neutron Star - Blackhole Connection, edited by C. Kouveliotou, J. van Paradijs & J. Ventura, Elounda, Crete, Greece
Morini, M., Robba, N. R., Smith, A. & van der Klis, M. 1988, ApJ, 333, 777
Murakami, T., Tanaka, Y., Kulkarni, S. R., et al. 1994, Nature, 368, 127
Oosterbroek, T., Parmar, A. N., Mereghetti, S. & Israel, G. L. 1998, A&A, 334, 925
Parmar, A. N., Oosterbroek, T., Favata, F., et al. 1998, A&A, 330, 175
Rho, J. & Petre, R. 1997, ApJ, 484, 828
Rho, J. & Petre, R. 1993, American Astronomical Society Meeting, 183, 101.07
Ruderman, M., Zhu, T. & Chen, K. 1998, ApJ, 492, 267
Sanbonmatsu, K. Y. & Helfand, D. J. 1992, AJ, 104, 2189
Sarma, A. P., Goss, W. M., Green, A. J. & Frail, D. A. 1997, ApJ, 483, 335
Seward, F. D., Charles, P. A. & Smale, A. P. 1986, ApJ, 305, 814
Smith, D. A., Bradt, H. V. & Levine, A. M. 1999, ApJ, 519, L147
Sonobe, T., Murakami, T., Kulkarni, S. R., Aoki, T. & Yoshida, A. 1994, ApJ, 436, L23
Sugizaki, M., Nagase, F., Torii, K., et al. 1997, PASJ, 49, L25
Torii, K., Kinugasa, K., Katayama, K., Tsunemi, H. & Yamauchi, S. 1998, ApJ, 503, 843
van Kerkwijk, M. H. 2000, HEAD, 32.3601
Vancura, O., Blair, W. P., Long, K. S. & Raymond, J. C. 1992, ApJ, 394, 158
Vasisht, G., Frail, D. A. & Kulkarni, S. R. 1995, ApJ, 440, L65
Vasisht, G. & Gotthelf, E. V. 1997, ApJ, 486, L129
Vasisht, G., Kulkarni, S. R., Frail, D. A. & Greiner, J. 1994, ApJ, 431, L35
Williams, R. M., Chu, Y., Dickel, J., et al. 1999, ApJS, 123, 467
Woods, P. M., Kouveliotou, C., van Paradijs, J., et al. 1999a, ApJ, 519, L139
Woods, P. M., Kouveliotou, C., van Paradijs, J., et al. 1999b, ApJ, 524, L55
Woods, P. M., Kouveliotou, C., Finger, M. H., et al. 2000, ApJ, 535, L55
Yusifov, I. M., Alpar, M. A., Gök, F., Guseinov, O. H. 1995, The Lives of the Neutron Stars, edited by M. A. Alpar, Ü. Kızıloğlu, J. van Paradijs, Kluwer, Dordrecht, p.201